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Effect Of Coating Thickness On The Microstructure And Mechanical Properties Of AL-SI (LM6) Alloy Lost Wax Casting

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ABSTRACT

In the work, the effect of slurry and stucco coating thickness on the microstructure and mechanical properties of Al-Si alloy (LM6) produced using the investment casting technique was investigated. A ceramic mold with four different layers (3, 4, 5 and 6 layers) of thickness was prepared using aluminum oxide (Al_2O_3) together with slurry and stucco. The result shows that the highest tensile strength value obtained from the three layers of coating is 161.67 MPa. Furthermore, an additional layer of coating thickness does not affect the structure of the aluminum alloy (LM6). The microstructure pattern shows an eutectic silicon formation on the wall of the mold at a higher intensity compared to the center. The results also showed that coating thickness has a significant effect on the microstructure located between the wall and the center. Heat transfer of the thinner coating is improved compared to the thicker coating. Indirectly, the formation of high density needle silicon on the wall gives better strength to the alloy.

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Introduction

In 2015, aluminium utilization in the automotive industry was predicted to increase up to 340 kg per vehicle by considering its use in a vehicle's body panel, engine parts and structure application [1]. Investment casting, also known as lost wax casting or precision casting is widely used for the production of complex geometries of ferrous and non-ferrous metal products. It can produce dimensionally accurate, intricate and high-quality shape components with a good surface finish. It is generally used to produce small, thin walled castings with wax as its pattern medium [2, 3]. Apart from these advantages, it also exhibits very low surface roughness compared to sand casting components, thus reducing machining costs [8].

Jiang et. al., 2014 [9] studied the wall thickness of A356 aluminium alloy and had found that the α-Al phase and eutectic silicon particles evolve from fine dendrite to coarse dendrite and from a fine fibrous structure to a coarse plate-like structure. Other techniques such as lost foam casting which is similar to investment casting also gives near net shape products with less machining required. Other researchers investigated the pattern coating thickness on lost foam casting. M. Karimian et. al., 2012 [4] examined the effect of thickness on lost form casting with two parameters of dipping time, and found that increasing the slurry viscosity or dipping time gives significant influence on the casting's integrity and microstructure. Thinner coating produces more pores, which facilitate gas escape and as a result, produces better mold filling [4]. On the other hand, Zych J., 2013 [5] developed a new method to measure the permeability of investment casting ceramic mold and found that the possible coating number is no less than five layers of coatings. However, H. Jafari, 2014 [3] implemented 3 to 6 layers of coating with zircon flour ($ZrSiO_4$) as slurry and colloidal silica (SiO_2) as a binder to investigate the quality and integrity of a product's internal surface. Meanwhile, S.Z. Mohd Nor, 2015 [8] explored the effects of dewaxing and burnout temperature used in the block mold process for copper alloy casting using the investment casting technique as a medium [5].

Previous studies indicated that aluminum oxide (Al_2O_3) is one of the least reactive and economic mold materials for the lost wax casting of aluminum alloy. The purpose of this paper is to outline the methodology of an aluminum oxide's (Al_2O_3) ceramic mold system that is suitable for the lost wax casting of Al-Si alloy. The effect of coating thickness on the mechanical properties and microstructure of Al-Si alloy is investigated.

Experimental Set Up

Wax and Ceramic Mold Preparation

Wax was poured into an aluminum mold to obtain the shape of tensile test specimens with sprue and runner in the middle. The tensile test specimens were designed according to the ASTM B557M shown in Figure 1. The center sprue mold shown in Figure 2 is the main entry for the wax before it is distributed into the cavity. Once wax was poured into the aluminum mold, it was assembled with the other wax components on the center sprue to form a casting cluster or wax pattern tree as shown in Figure 3. Next, the entire wax pattern tree was dipped into the ceramic slurry (Al_2O_3) set at 20-22s using Zahn cup No. 4. The thickness of the mold was adjusted according to the coating layer at 1-2 mm per layer using fine alumina-silicate sand (Al_2SiO_5) as shown in Figure 7. The process was repeated with 3, 4, 5 and 6 layers of coating. After complete drying, the mold was dewaxed and fired at 200°C and 800°C for 30 and 60 min, respectively.

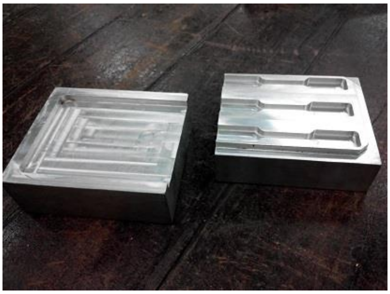


Figure 1: Tensile test specimen mold

Figure 2: Center spruemold

Melting and pouring

An ingot of commercial LM6 alloy was placed in a crucible and melted in a resistance heating furnace up to 700±5°C melting temperature. Meanwhile, the ceramic mold was preheated in the firing furnace up to 850°C. After the ingot was melted, it was poured into the hot ceramic mold at 680°C pouring temperature and was let to cool at room temperature. After the as-cast was cooled sufficiently, mold shells were chipped away from the as-cast as shown in Figure 4. Tensile tests were performed at room temperature using a universal tensile test machine, Instron 5969 and a macro hardness test were performed using the Rockwell hardness test (HRB) of 100kgf. The chemical composition of aluminum alloy (LM6) was described in Table 1.

Figure 3: Wax pattern tree

Figure 4: As-cast samples

Table 1: Chemical Composition of LM6

Element	Si	Fe	Cu	Mn	Mg	Ni	Zn	Al
Percent (%)	11.5	0.6	0.1	0.5	0.1	0.1	0.1	Bal

Results And Discussion

Tensile Strength

The highest value obtained for the average maximum tensile stress was 161.67 MPa, which was the result for the 3-layer coating thickness, while the lowest value for the average maximum tensile stress was 136.67 MPa for the 6-layer coating thickness. The maximum values of tensile stress for the 4 and 5- layer coating thickness was 154.67 MPa and 155 MPa respectively, as shown in Figure 5. All of the tensile strength values were referred to S. Sulaiman et al's (2013) [1] study as reference. The trend of tensile value decreases as coating thickness was increased, as shown in Figure 6. Although the 3-layer coating thickness had the highest tensile strength, its yield strength was low at 76 MPa compared to the 5-layer coating thickness which was the highest at 108 Mpa, followed by the 4-layer coating thickness. Table 2 shows the detailed tensile properties of each coating thickness.

From the results provided in Table 2, it proves that thin coatings of the ceramic mold give a significant effect in the strength of aluminum alloy, mainly because due to the heat transfer in between the mold and the molten metal. Figure 7 shows that heat from the cavity was distributed very fast until the end of the last coating, and it is shown by the colour of the coating that changes from dark to bright according to the direction of the red arrow showing from cavity to mold.

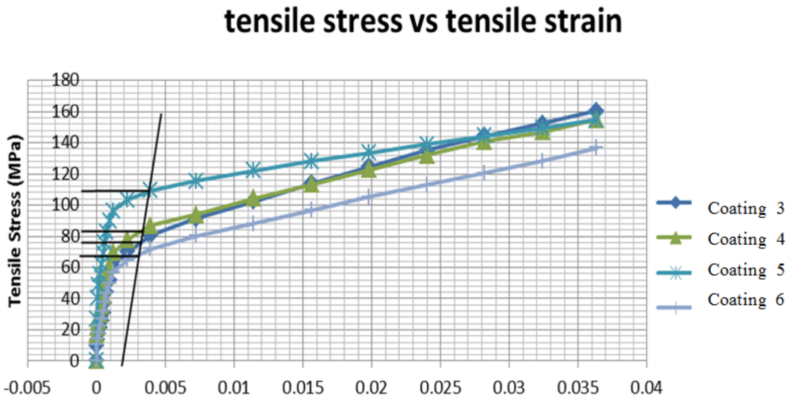


Figure 5: Tensile Stress vs Tensile strain of each coating thickness

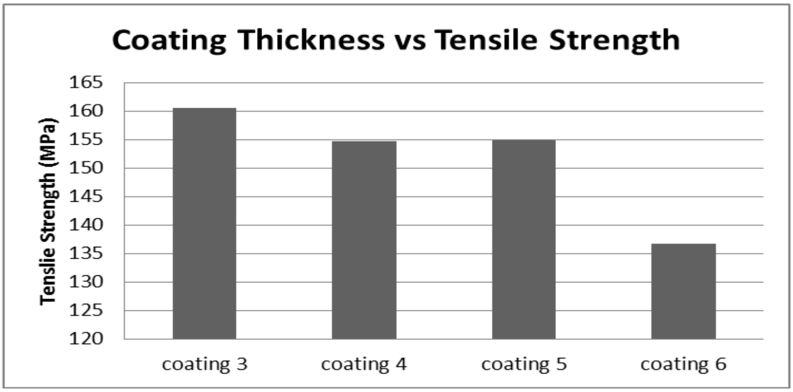


Figure 6: Tensile Stress vs Tensile strain of each coating thickness

Table 2: Tensile properties for each coating

Layer of coating	Tensile stress MPa	Average of yield strength MPa	Modulus of elasticity GPa	Max load kN
3	161.67	76	52	27.16
4	154.67	84	88	25.98
5	155	108	64	26
6	136.67	68	80	22.96

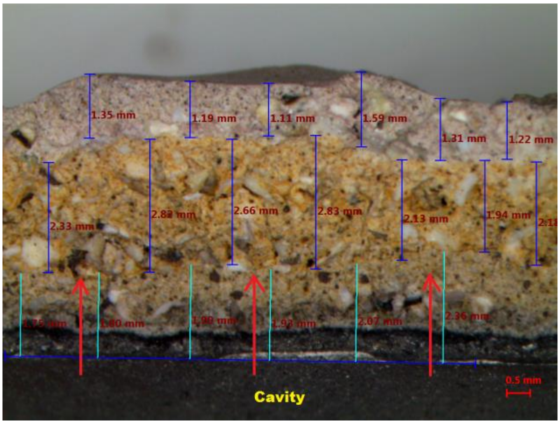


Figure 7: Heat distribution from mold cavity to mold wall

Macro Hardness

In this work, the Rockwell hardness with 100Kgf was measured to compare the hardness of each coating thickness. Two points of hardness were measured, which is near the wall and the centre of the samples. Figure 8 shows that hardness increases when the coating thickness was increased. The highest value was for the 6-layer coating with HRB 26.9 near to the wall and HRB 13.7 at the centre. The increase in hardness is mainly caused by the density of the Al matrix at the centre of the casting and the needle silicon formation on the wall as shown in Figure 10. Figure 8 shows the result of Hardness (HRB) vs Coating thickness.

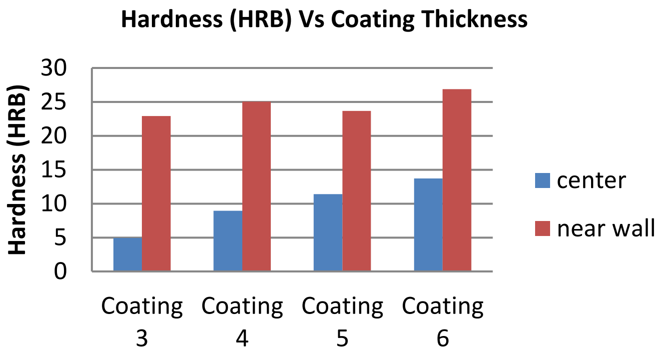
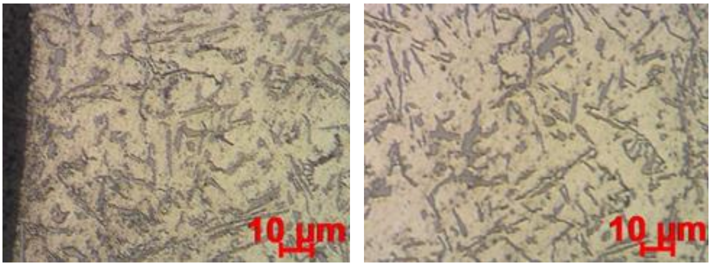


Figure 8: Hardness (HRB) vs coating thickness

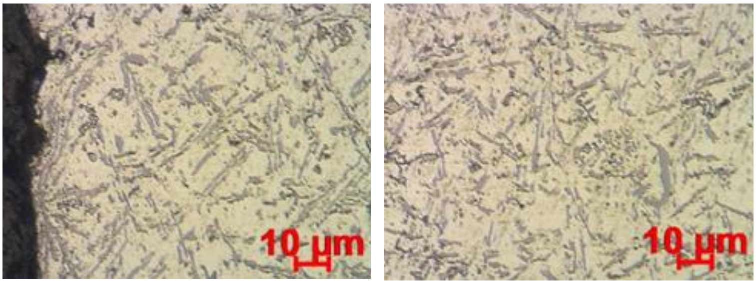
Microstructure

The formation of the needle eutectic silicon structure appeared to be at high intensity at the wall as shown in Figure 8a, and fairly intense at the center as shown in Figure 8b when using the 3-layer coating thickness. The morphology of the aluminum formation was almost the same as S. Farahany et. al (2016) with strontium as the modification element and needle flakes appearing at the microstructure [16]. Figure 9 shows the microstructure of the 5-layer coating thickness and its density of the needle silicon structure which started to decrease compared to the 3-layer coating. Figure 10 shows the silicon formation starting to get loose at the center of the casting. Heat transfer and gas permeability were recognized as potential factors affecting the decreased density of silicon formation in the center.



(a) (b)

Figure 8: (a) Wall of 3 layers coating (b) Center 3 layer coating



(a) (b)

Figure 9: (a) Wall of 5 layers coating (b) Center 5 layers coating

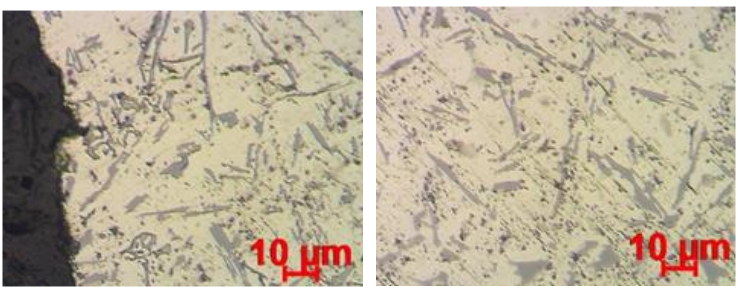


Figure 10: (a) Wall of 6 layers coating (b) Center 6 layers coating

Conclusion

In the present work, the effect of an important parameter of lost wax casting, namely the coating thickness of LM6 alloy was investigated. The following conclusions were drawn. The strength of the alloy starts to decrease when there are increments in the number of coating thickness. Furthermore, high eutectic silicon formation at the wall improves the bonding between grains. Thinner coating gives better strength to the alloy but not to the mold and increasing the coating thickness of the ceramic wall gives better hardness value to the alloy.

This project sparks interest in the investment casting industry into saving costs on raw material, especially in the purchasing of refactory material, which contributes the highest cost to the total production.

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